

Overview of RHIC e-lens study

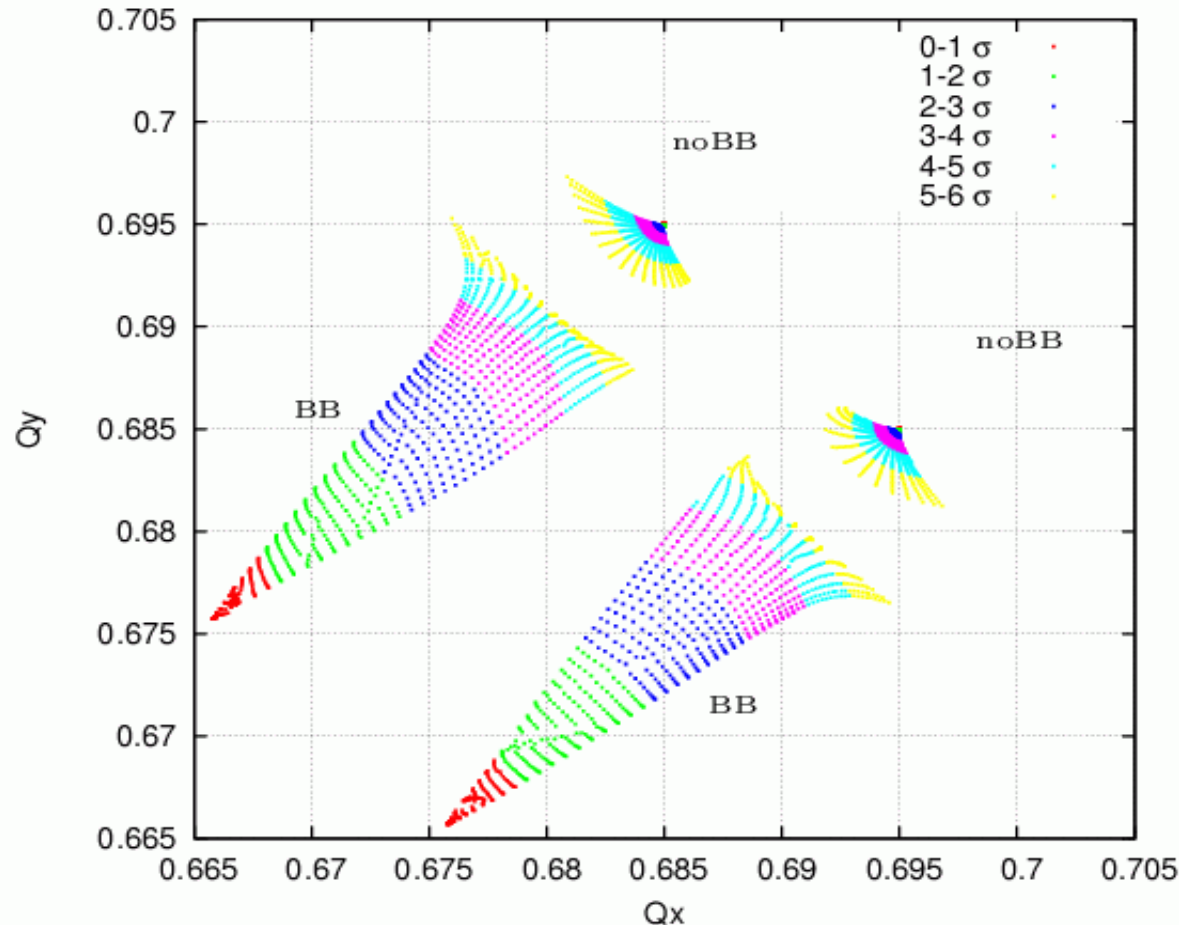
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E. Beebe, M. Okamura, A. Pikin

- 1. Motivation**
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(2008 RHIC MAC review meeting, Feb. 11-13, 2008, BNL)

Motivation

- Beam-beam generated tune shift and tune spread in the RHIC pp run



Tunefoot prints with
 $N_b=2.0e11$, beam-beam
at IP6 and IP8.

Beam-beam parameter:

$$\xi = -\frac{N_p r_0}{4\pi\epsilon_n}$$

To further increase bunch intensity, there will be no enough room between (2/3, 7/10) in the tune space to hold the head-on beam-beam generated tune shift and tune spread.

- **Head-on beam-beam compensation with electron lens**

- p-p bunch interaction:

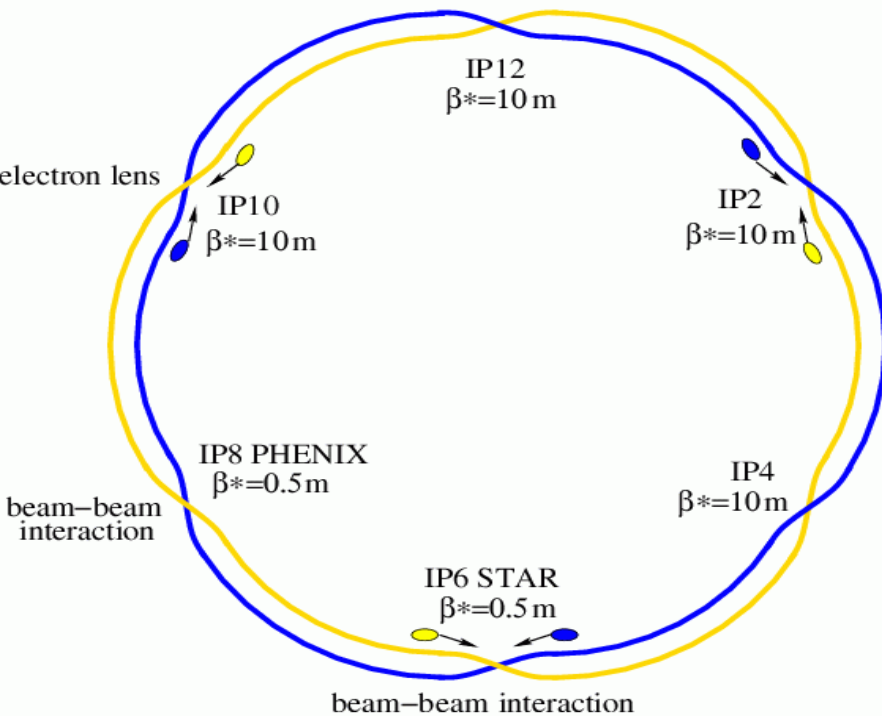
$$\begin{pmatrix} \Delta x' \\ \Delta y' \end{pmatrix}_{p-pbunch} = \frac{2N_p r_0}{\gamma r^2} (1 - e^{-\frac{r^2}{2\sigma_p^2}}) \begin{pmatrix} x \\ y \end{pmatrix}$$

$$\Delta Q_{x,y}|_{p-pbunch} = -\frac{N_p r_0 \beta^*}{4\pi \gamma \sigma_p^2} = -\frac{N_p r_0}{4\pi \gamma \epsilon_p}$$

- p-elens interaction:

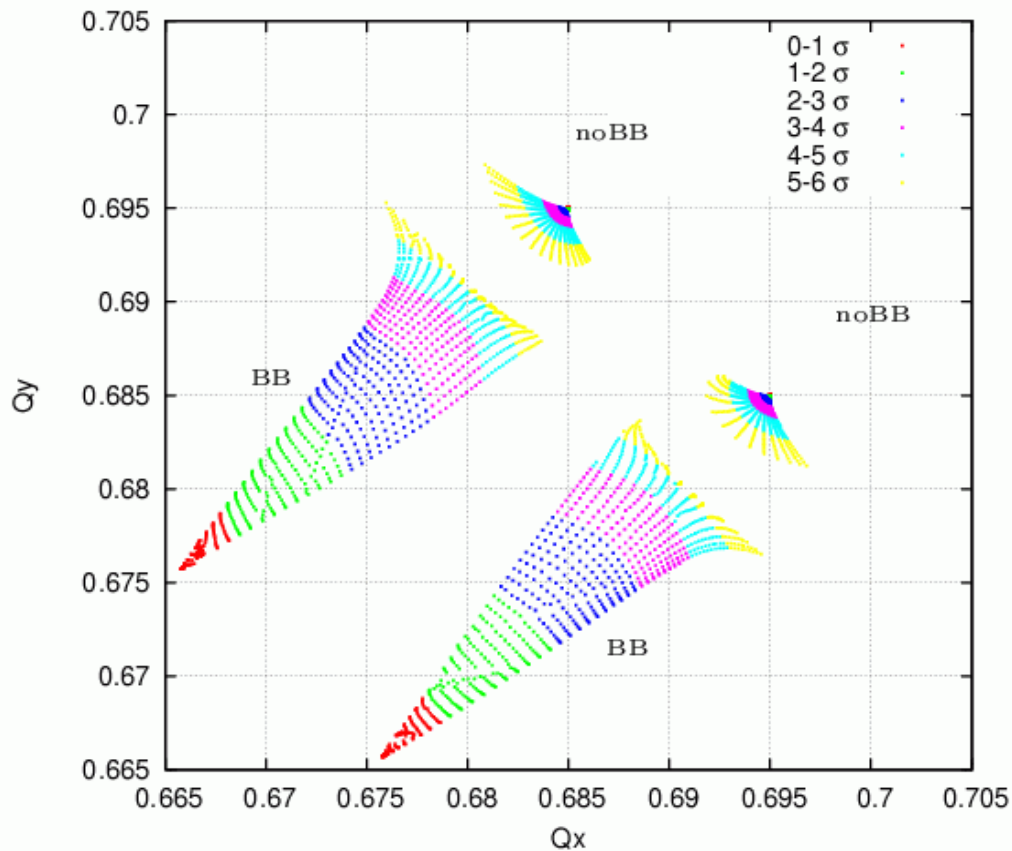
$$\begin{pmatrix} \Delta x' \\ \Delta y' \end{pmatrix}_{p-ebeam} = -\frac{2N_e r_0}{\gamma r^2} (1 - e^{-\frac{r^2}{2\sigma_e^2}}) (1 + \beta_e) \begin{pmatrix} x \\ y \end{pmatrix}$$

$$\Delta Q_{x,y}|_{p-elens} = \frac{N_e r_0 \beta_{elens}}{4\pi \gamma \sigma_e^2} (1 + \beta_e) = \frac{N_e r_0}{4\pi \gamma \epsilon_e} (1 + \beta_e)$$

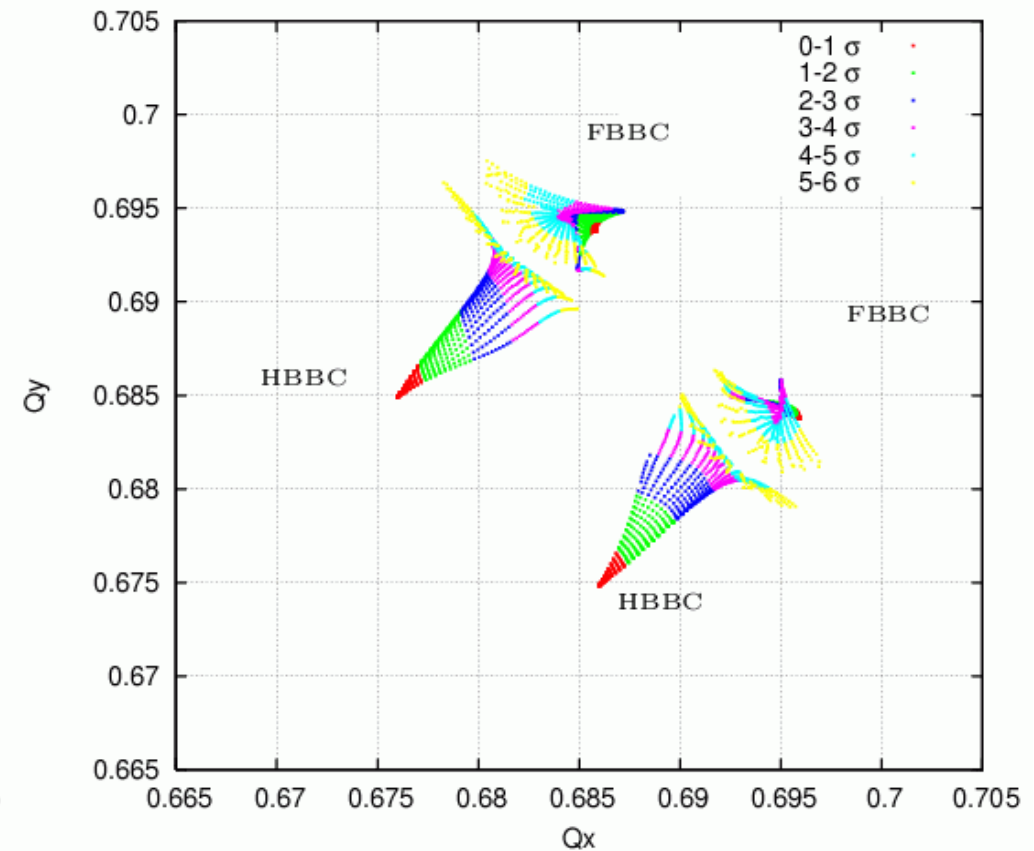


However, head-on beam-beam compensation hasn't been verified experimentally.

- Tune footprint with head-on beam-beam compensation in RHIC pp run



Without BBC



With BBC

From point of view of beam-beam tune shift and tune spread, head-on beam-beam compensation is very promising.

Parameters

▪ Parameters for proton beam

Table 1: Parameters for the proton beams

quantity	unit	value
lattice		
ring circumference	m	3833.8451
energy	GeV	250
relativistic γ	-	266
beam-beam collision points	-	IP6, IP8
beam-beam compensation point	-	IP10
$\beta_{x,y}^*$ at IP6 and IP8	m	0.5
$\beta_{x,y}^e$ at IP10	m	10
$\beta_{x,y}^*$ at all other IPs	m	10
proton beam		
particles per bunch N_p	-	2×10^{11}
normalized transverse rms emittance $\epsilon_{x,y}$	mm·mrad	2.5
transverse rms beam size at collision points $\sigma_{x,y}^*$	mm	0.068
transverse rms beam size at e-lens $\sigma_{x,y}^e$	mm	0.31
transverse tunes (Q_x, Q_y)	-	(28.695, 29.685)
chromaticities (ξ_x, ξ_y)	-	(1, 1)
beam-beam parameter per IP $\xi_{p \rightarrow p}$	-	-0.01
longitudinal parameters		
		Acceleration rf system Storage rf system
harmonic number	-	360 2520
rf cavity voltage	kV	300 3500
rms longitudinal bunch area	eV·s	0.17 0.17
rms momentum spread	-	0.14×10^{-3} 0.43×10^{-3}
rms bunch length	m	0.44 0.15

- **Parameters for electron beam**

Table 2: Parameters of RHIC e-lenses.

quantity	symbol	unit	value
electron beam parameters			
electron kinetic energy	K_e	keV	5
electron speed	$\beta_e c$...	0.14c
electron transverse rms size	σ_e	mm	0.57
effective e-lens length	L_{elens}	m	2.0
full head-on BB compensation			
total electron particles in the e-lens	N_e	-	3.5×10^{11}
electron beam current	I_e	A	1.2

DC low energy electron beam with transversely Gaussian profile.
The compensation region is covered by superconducting solenoid
~6.5T and ~2 m long.

- **Installation of RHIC e-lenses (BEL and YEL)**

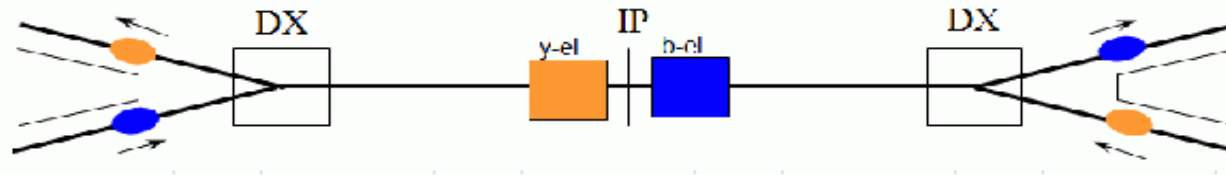


Figure 2: RHIC e-lenses at IP10.

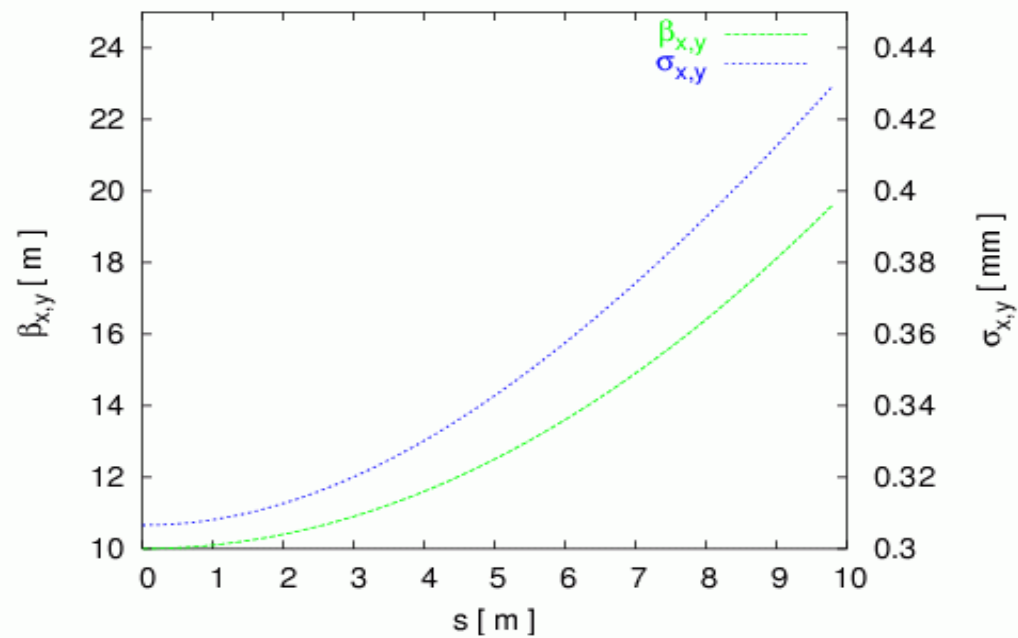
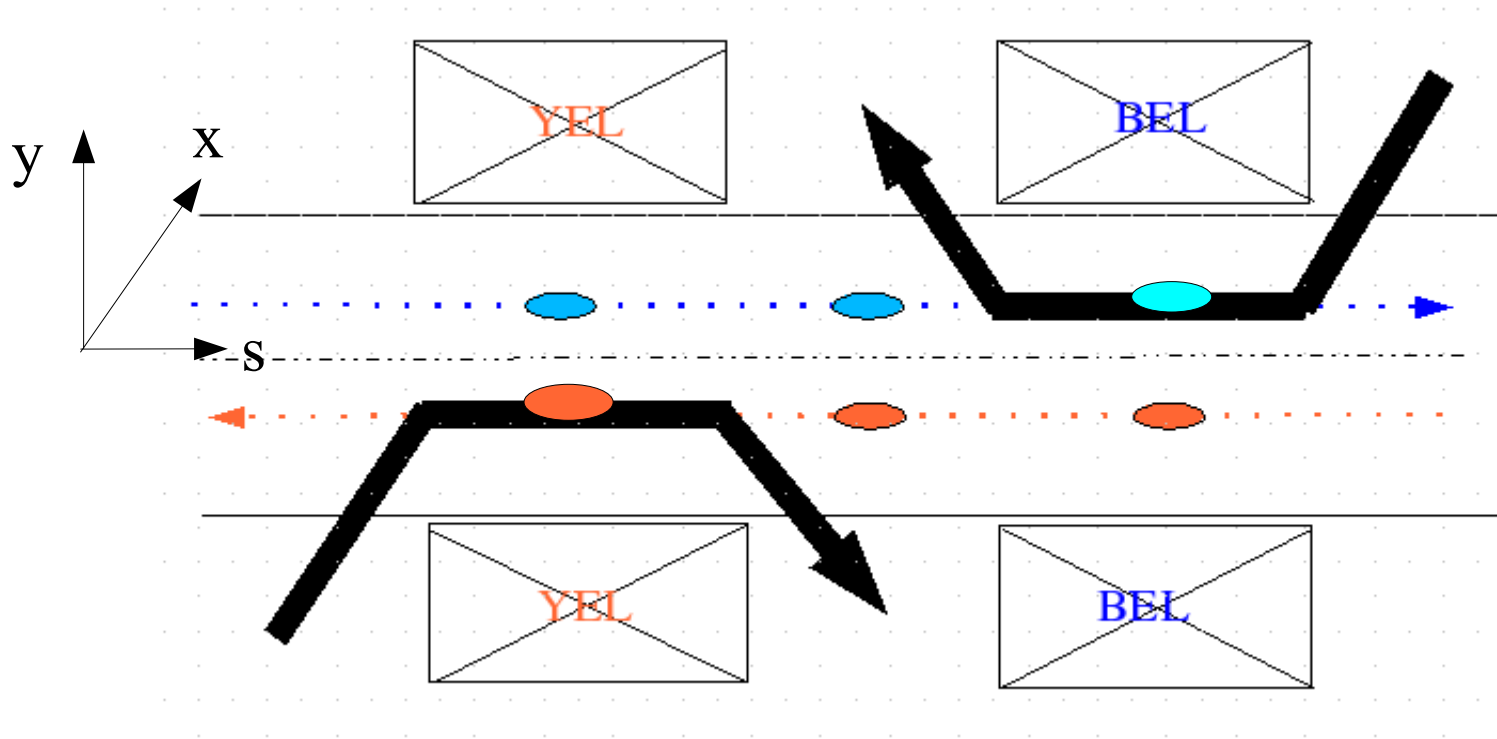


Figure 3: Beta function and proton beam size versus the distance from IP10. In this calculation, the rms transverse emittance of the proton beam is assumed to be 2.5 mm-mrad.

- **Beam paths around e-lenses**



Proton beams are vertically separated around 5~10 mm.
Electron beams are dumped on the IP10 side.

Questions

▪ Questions for accelerator physics

Does the head-on beam-beam compensation

- reduce beam-beam tune shift and spread? YES
- increase store dynamic aperture? NO
- reduce emittance growth rate?
- increase collisional beam lifetime?
- Have potential to increase beam-beam parameter ?



With 50% increased bunch intensity, if head-on beam-beam compensation doesn't significantly deteriorate the collision proton beam lifetime, the collision luminosity will be doubled.

- **Scope of study for e-lens engineering design (A. Pikin)**

- 1) Study applicability of the existing Fermi-lab electron gun solution for the RHIC e-lens.
- 2) Study methods of the electron beam transverse position control. Requires 3D simulations of the magnetically confined electron beam in all regions of E-lens.
- 3) Design electron collector with capability to extract ions from the interaction region for diagnostics purposes.
- 4) Design diagnostics tools for measuring electron beam transverse position in the interaction region, measuring the transverse profile of the electron beam.
- 5) Analyze methods of automatic control of the electron beam position in the interaction region.
- 6) Analyze effect of not straight magnetic field and electron beam on the circulating ion beam, come up with the requirements to the quality of the magnetic field of the main solenoid, analyze methods of magnetic field measurements and design appropriate instrumentation.

▪ **Based on above questions, we are carrying out studies in following directions**

- Single particle stability with BBC
- Multi-particle simulation with BBC
- Effects of noises in electron beam
- Design of RHIC e-lens system
- Other studies:
 - chaotic boundary,
 - phase advances between IPs,
 - long-range beam-beam,...

Organizations

- **Physicists involved in this study**

Y. Luo and W. Fischer, Parameters and Layout

Y. Luo and N. Abreu, Single particle stability

Y. Luo and N. Abreu, Multi-particle trackings

Y. Luo and N. Abreu, Effects of errors and noises

G. Robert-Demolaize, SixTrack code modifying

A. Pikin, M. Okamura, E. Beebe, E-lens design

C. Montag, Impact on eRHIC

- **Time line for this study**

July, 2007,	team officially formed
Feb, 2008,	single particle stability completed
April, 2008,	effects of errors and noises
April, 2008,	multi-parcle tracking results
April, 2008,	version 1 of e-lens system design
May, 2008,	pre-review
May-July, 2008,	further studies
August, 2008,	review of this study

Followed by decision making.

- **Simulation codes and computation facilities**

SixTrack is used for particle trackings in this study.

It is 6-dimensional optics tracking code.

Beam-beam is treated with 4-D or 6-D weak-strong model.

All nonlinear elements are treated as thin lenses.

All linear elements are treated as thick lenses.

nonlinearity in interaction regions and chromatic sextupoles included.

Computation facilities:

A huge CPU time is needed for multi-particle trackings. Currently we are use cluster.bnl.gov. Hopefully we can use CERN computing facilities.

- **Single Particle stabilities**

Following quantities are calculated to indicate long-term stability.

- 1) tune footprints
- 2) tune diffusion
- 3) action diffusion
- 4) Lyapunov exponent
- 5) 10^6 turn dynamic aperture
- 6) Resonance driving terms (RTD)
- 7) Overlapping of resonances in phase space
- 8) ...

▪ Conclusions from single particle stability study

1) Head-on beam-beam compensation does reduce both beam-beam tune shift and tune spread.

2) Head-on beam-beam compensation help stabilize the particles in the bunch core. However, it affects the stability of the particles with large amplitudes.

3) Full head-on beam-beam compensation is not a good choice. The realistic compensation may be half beam-beam compensation.

4) Multi-particle tracking is needed to check the effect of head-on beam-beam compensation in the RHIC.

how helpful to the core particles--> emittance growth
how harmful to the bunch tail --> beam lifetime

- **Multi-particle particle trackings**

In current study,

- 1) 12800 macro-particles with Gaussian distribution
- 2) Tracking up to 10^7 turns , ~ about 2 mins. of real machine time
- 3) 6-dimensional
- 4) calculate the emittance growth and beam lifetime every 10^5 turns

Difficulties in this study,

- 1) How to generate initial particle coordinates to give meaningful results
- 2) How to accurately calculate emittance and lifetime
- 3) The achieved emittance calculation resolution is about 0.05%.
- 4) How to interpret the particle lose
- 5) migration of particles also important to check

- **Effects of noises in electron beam**

SixTrack is also modified to track with noises of the following quantities

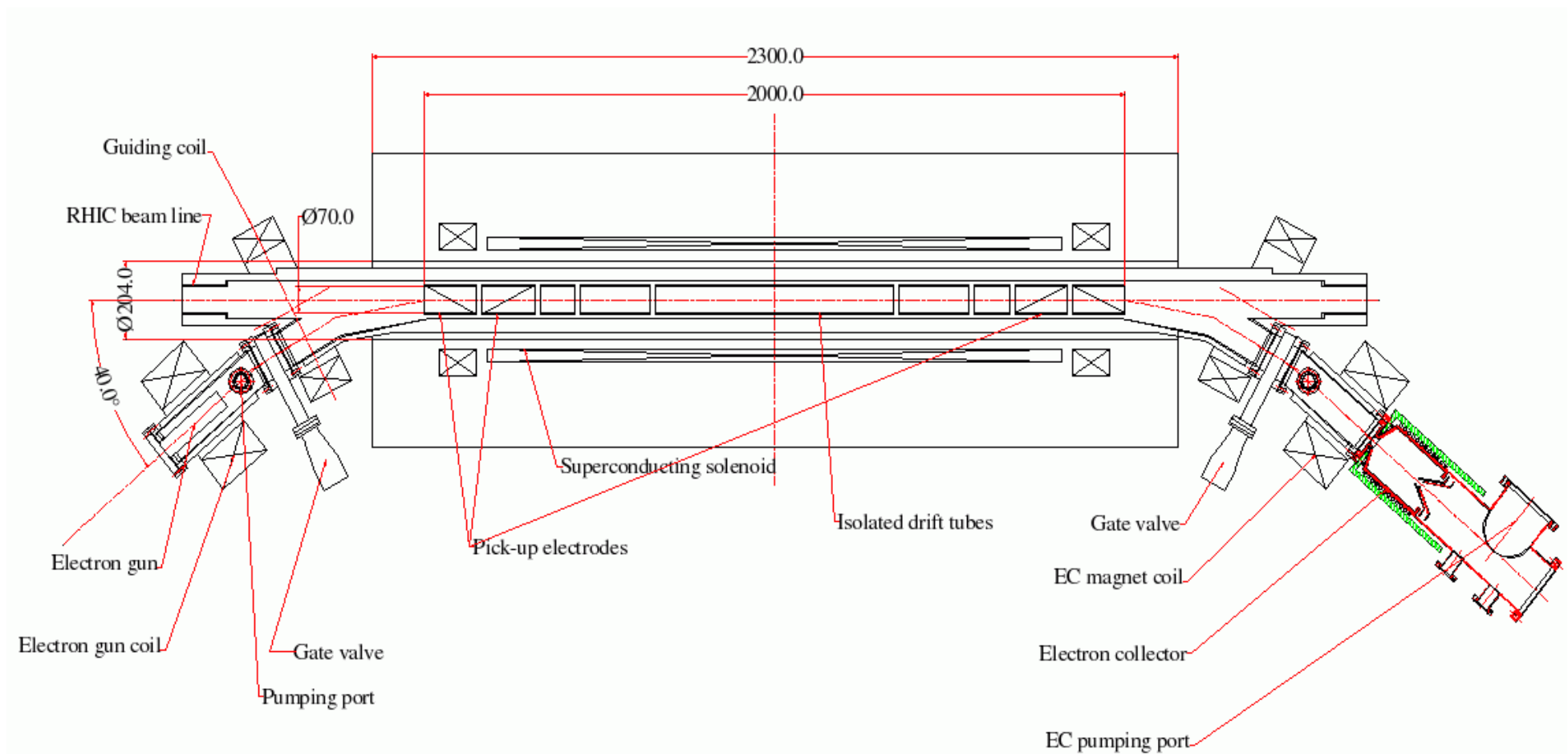
- 1) electron beam intensity
- 2) offsets of beam-beam interaction
- 3) electron beam transverse sizes

.....

All these quantities can be changed on turn-by-turn basis in simulation. These changes can be static, random, or sin wave.

This study is to be launched soon and will be completed in a short time.

- **Design of RHIC e-lenses** (coordinated by A. Pikin)



Layout of e-lens system by A. Pikin

Summary

1. Head-on beam-beam compensation reduces head-on beam-beam interaction generated tune shift and tune spread. Therefore it is promising to improve luminosity by increasing bunch intensity.
2. It is found in the study of single particle stability that head-on beam-beam compensation will stabilize the particles in the bunch core but affect the stability of particles in bunch tail.
3. Multi-particle tracking is in progress to calculate the proton beam's emittance growth rate and beam lifetime with head-on beam-beam compensation.
4. The nominal parameters of the RHIC e-lenses are likely achievable. However, noises in the current, position control of electron beam should be paid attention. Position feedback system may be needed.
5. To meet the goal of this study, more manpower is needed. And the computation facility at CERN will be very helpful for multi-particle tracking.